Development of Indoor Air Pollution Concentration Prediction by Geospatial Analysis

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Abstract. People living near busy roads are potentially exposed to traffic-induced air pollutants. The pollutants may intrude into the indoor environment, causing health risks to the occupants. Prediction of pollutant exposure therefore is of great importance for impact assessment and policy making related to environmentally sustainable transport. This study involved the selection of spatial interpolation methods that can be used for prediction of indoor air quality based on outdoor pollutant mapping without indoor measurement data. The research was undertaken in the densely populated area of Karees, Bandung, Indonesia. The air pollutant NO_2 was monitored in this area as a preliminary study. Nitrogen dioxide concentrations were measured by passive diffusion tube. Outdoor NO_2 concentrations were measured at 94 locations, consisting of 30 roadside and 64 outdoor locations. Residential indoor NO_2 concentrations were measured at 64 locations. To obtain a spatially continuous air quality map, the spatial interpolation methods of inverse distance weighting (IDW) and Kriging were applied. Selection of interpolation method was done based on the smallest root mean square error (RMSE) and standard deviation (SD). The most appropriate interpolation method for outdoor NO_2 concentration mapping was Kriging with an SD value of 5.45 $\mu g/m^3$ and an RMSE value of 5.45 $\mu g/m^3$, while for indoor NO_2 concentration mapping the IDW was best fitted with an RMSE value of 5.92 $\mu g/m^3$ and an SD value of 5.92 $\mu g/m^3$.

Keywords: *Bandung; urban air quality; Kriging; IDW; nitrogen dioxide.*

1 Introduction

Urban air quality in Indonesia is dominantly influenced by transportation activity. Many gaseous pollutants are emitted from vehicle exhaust, such as NO_x, SO_2, hydrocarbon and particulate matter. The most common air pollutant that is emitted by the vehicle combustion process is NO_x. This pollutant is formed in the combustion process from the air that reacts with oxygen at high temperature. Oxides of nitrogen pollution is a concern because it is related to respiratory diseases and can become a catalyst for ground level ozone formation.

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Oxides of nitrogen pollution from transportation activity contribute a larger portion of total air pollution in urban areas compared to emissions from the industrial and domestic sectors. More than a decade ago, results of air quality monitoring in 5 Indonesian cities indicated that the NO_x portion contributed by the transportation sector was 75% in Jakarta, 66.6% in Surabaya, 56.3% in Bandung, 82.5% in Semarang and 76.1% in Medan [1]. From roadside monitoring in Bandung it was reported that NO_x concentrations exceeded the ambient air quality standard at 16 sites, reaching a level of more than 450 $\mu g/m^3$ [2].

As mentioned before, many respiratory diseases are associated with exposure to NO_x. Several researchers have found that the most effective exposure to air pollutants is in the indoor environment. Thus, outdoor air quality management is also important because it affects indoor air quality. Some researchers have found that the ambient environment can affect the indoor environment. In many cases it was discovered that outdoor air pollution is the main source of the indoor air quality deterioration [3]. The influence of outdoor air quality on indoor air quality is demonstrated by an indoor to outdoor (I/O) ratio with a value of less than 1 [4]. An I/O value of less than 1 is common in areas with a tropical climate. Yang, *et al.* [5] have found that the I/O ratio in Brisbane, Australia was 0.82 ± 0.41 and Lawrence, *et al.* [6] found an I/O value of 0.58 in Agra, India.

Efforts to manage roadside air quality are done within the framework of Environmentally Sustainable Transport (EST). One of its aims is to decrease the impact of transportation on public and environmental health. Roadside air quality monitoring therefore should be conducted in order to fulfill air quality management within the EST framework. However, as the impact on the receptors is more important, prediction of indoor air quality that is affected by outdoor pollutant concentrations originating from road sources is a prime concern. In order to develop a method to predict indoor exposure based on outdoor pollutant concentrations, for the present research ambient concentration data were collected and techniques to obtain the appropriate mapping method were investigated.

There are many methods that can be used for predicting the spatial variation of air pollution. Zou, *et al.* [7] divide air quality exposure models for predicting air pollution concentrations to which the population is exposed into three groups: proximity models, air dispersion models, and hybrid models. Proximity models are based on the assumption that exposure at locations nearer to an emission source is higher than at locations more remote from the source. Air dispersion models predict the air pollution concentration by numerically processing emission and meteorological data. Hybrid models are a combination of different models to predict the air pollution concentration.

Air dispersion models can provide a higher-resolution analysis than proximity models. The problem with developing air dispersion models, especially in Indonesia, is that the process to acquire the data is more complicated and costly and, in the worst case, data are not available/retrievable. Therefore a new and reliable method for predicting air pollution concentrations should be developed.

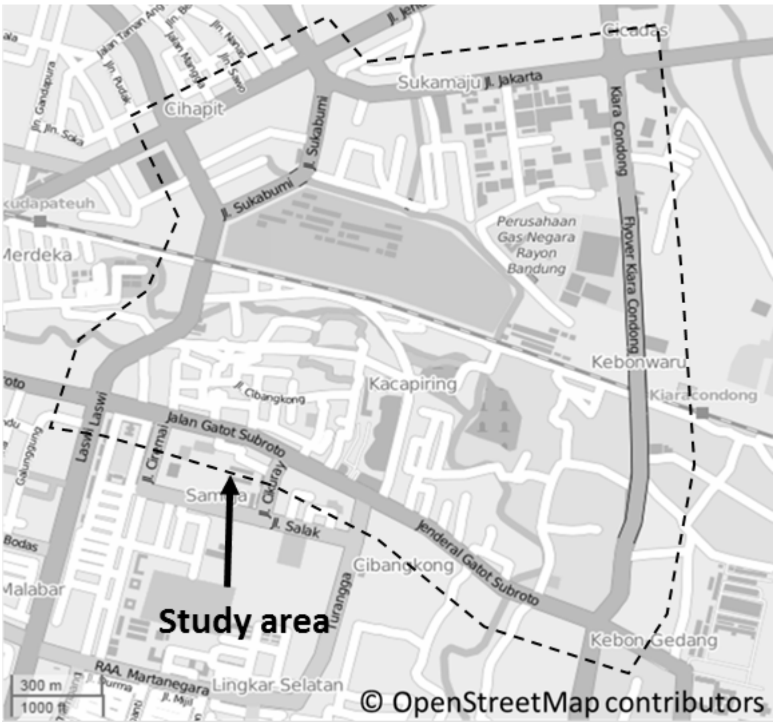

Figure 1 Study Location in Karees Area, Bandung, Indonesia (Source: openstreetmap.org).

Through the use of low-cost ambient outdoor measurement, the prediction model in this study has the advantage that it does not require as many input data as conventional methods. In terms of indoor concentration prediction, another important reason is that it is more practical to conduct outdoor (roadside and ambient) monitoring rather than asking permission at every house to undertake indoor monitoring.

To obtain a high-resolution map, spatial interpolation is conducted. This geostatistical method is used for spatial analysis and provides a means to represent spatially continuous phenomena [8]. Spatial interpolation has been used in several studies to predict pollutant concentration values for areas without data. The Kriging method and the regression method [9] are methods that are commonly used and have formed the basis for environmental pollution mapping in recent years. Several studies found that the most common methods in the mapping of air quality data are inverse distance weighting methods [10-13] and Kriging methods [12-16].

This paper elaborates the selection of interpolation methods that were used to predict indoor and outdoor NO_2 concentration values in an area without measurement data in the Karees area, Bandung, Indonesia. Method selection was based on root mean square error (RMSE) and standard deviation (SD) values obtained from every interpolation method investigated. The selected mapping subsequently was the basis for analyzing the correlation between outdoor and indoor pollutant concentrations, and furthermore it was used to predict the indoor concentration from the outdoor concentration data.

2 Methods

2.1 Study Location

This study was conducted in Karees area, which has a high density of population and high traffic activity. The selected roads were: Jalan Laswi, Jalan Sukabumi, Jalan Gatot Subroto, Jalan Kiara Condong, Jalan Jakarta and Jalan Ahmad Yani (Figure 1).

2.2 Determination of Sampling Points

To obtained a high-resolution pollutant dispersion model by geospatial analysis, the sampling locations should be spatially distributed. To ensure the sampling locations were distributed spatially, in this study a 5” x 5” grid was used. This grid size is appropriate for small-scale spatial studies.

Secondary and primary data were used for geospatial analysis. The secondary data of NO_2 concentrations were obtained from 54 outdoor locations, of which 30 were roadside locations [17], paired with house’s porches (outdoor) and house’s living rooms (indoor) at 24 locations [18]

Primary NO_2 indoor and outdoor concentration data were obtained from 40 residential buildings near a road. The distance from the road was varied to investigate the pollutant dispersion from transportation activity. These data were combined with the secondary data from a previous study to obtain more points for developing the spatial analysis.

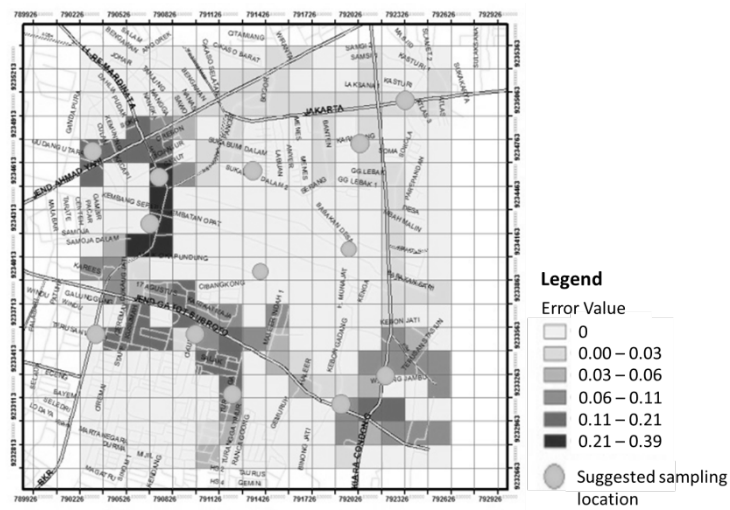

Figure 2 Error Value and Recommended Sampling Locations (Source: Kurniawati [19]).

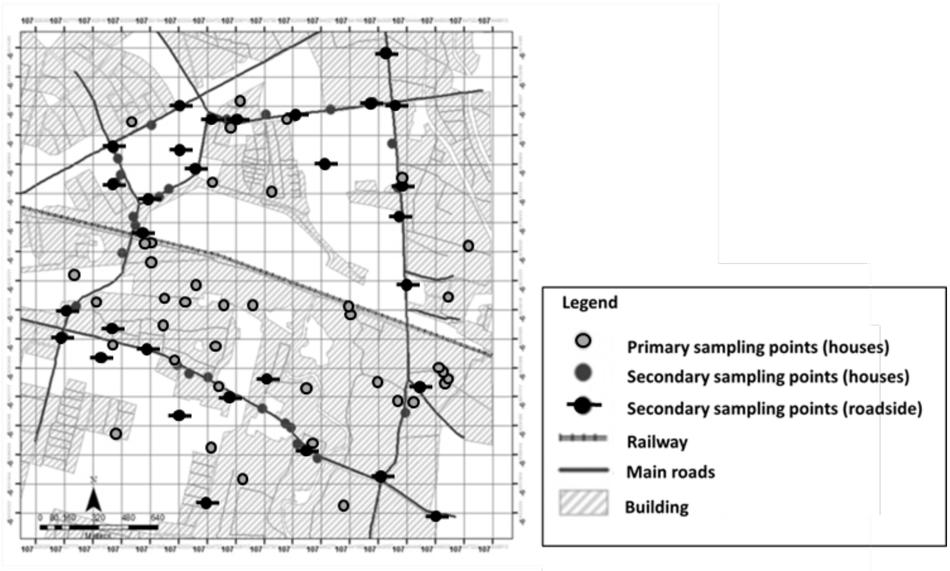

Figure 3 Sampling Point Locations Determined for Mapping Extrapolation.

The primary sampling locations for this study were determined based on the previous sampling locations as well as by the previous spatial interpolation analysis of NO_2 roadside measurement data from Kurniawati (2009) [19]. Some locations from [19] had high error values due to a lack of measurement data (Figure 2). For a higher resolution of concentration data, in this study more sampling points were placed in the areas with a high error value, in order to improve the spatial distribution (Figure 3).

2.3 NO_2 Measurement

Nitrogen dioxide passive samplers were used to measure NO_2 indoor and outdoor concentrations. A Palmes-type acrylic passive diffusion tube with a diameter of 11.0 mm and a length of 71 mm was used. A solution of 50% TEA/acetone was used as the NO_2 absorbent. The tubes were exposed at the sampling points for a duration of 1 week. Temperature and pressure data were taken at the beginning and end of the sampling period.

2.4 Data Analysis

Spatial data analysis was carried out with ArcGIS software based on a 5”-by-5”grid resolution. This is the finest resolution of grid systems used in Indonesia [20]. The grid system was developed with the aim to simplify the updating process of the environmental data. The systematically structured environmental database will quicken analysis and assist the decision making process.

Inverse distance weighting (IDW) and Kriging were used in this research to extrapolate NO_2 concentrations. Both methods are widely used for environmental data mapping [9,13,19]. Another consideration was that these methods have been found to have the least amount of interpolation errors [19]. They were chosen as the best two candidates based on a screening process using 4 different interpolation methods, i.e. IDW, Kriging, radial basis function and moving average of preliminary outdoor data, from the previous study [19].

3 Result and Discussion

3.1 Measurement Results

Figure 4 shows the NO_2 concentrations in the study area. The concentration is proportional to the size of each point, i.e. the larger the point, the higher the concentration. From Figure 4 and 5 it can be concluded that the highest concentrations were located near the roads. The smaller the distance from the house to the road, the higher the NO_2 concentration. The highest concentrations were found on Jl. A. Yani, Jl. Sukabumi, Jl. Laswi and Jl. Gatot Subroto. The average indoor NO_2 concentration in the study area was 35.58 $\mu g/m^3$ and the outdoor NO_2 concentration was 41.49 $\mu g/m^3$. The minimum and maximum NO_2 concentration values are listed in Table 1.

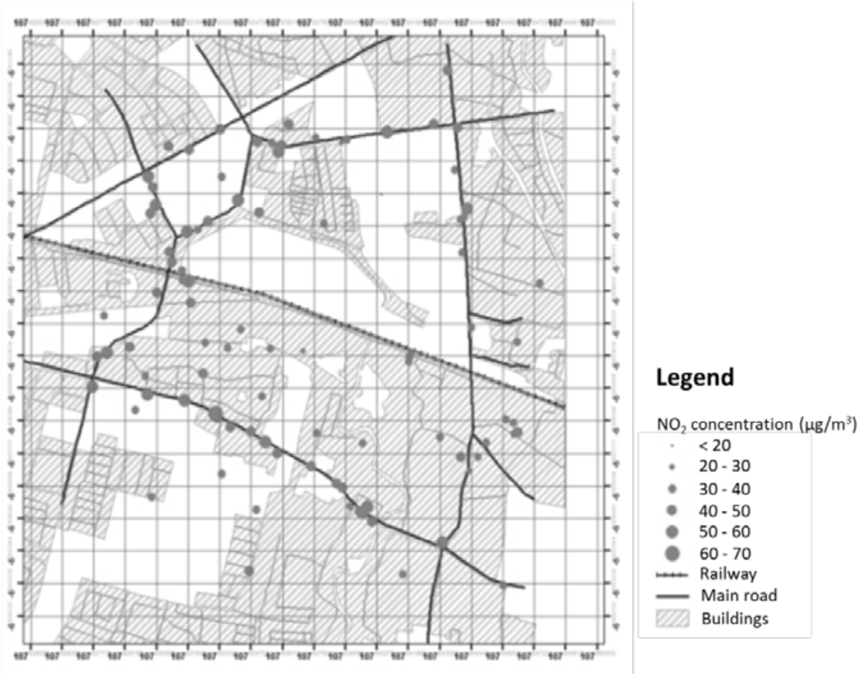

Figure 4 Distribution of Outdoor NO_2 Concentrations.

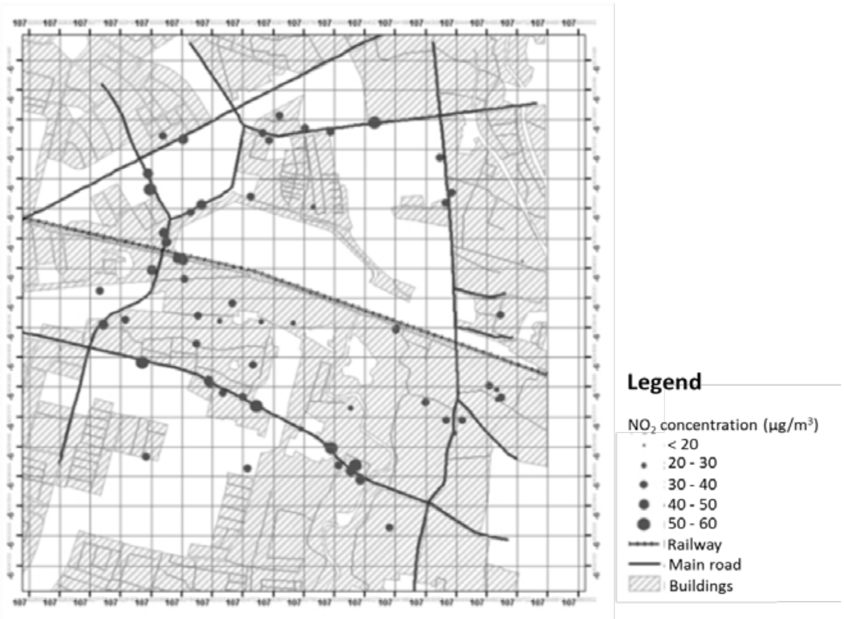

Figure 5 Distribution of Indoor NO_2 Concentrations.

Table 1 Maximum, Minimum and Average Concentrations of NO_2 in the Karees Area.

	Indoor **(µg/m^3)**	***Outdoor*** **(µg/m^3)**
Minimum value	15.43	18.19
Maximum value	56.27	61.10
Average value	35.58	41.49

The ratio of indoor to outdoor concentration (I/O) can be used for determining the influence of outdoor ambient air on the indoor ambient air. The I/O ratio was calculated from the measurement data. The I/O ratio shows the dominant source of pollution. Indoor sources are dominant if the I/O value is larger than 1. Conversely, an I/O ratio smaller than 1 indicates a major influence of outdoor sources on indoor air quality. The calculated I/O values are shown in Figure 6, the bold line representing the average I/O value. In this research the minimum value of I/O was 0.51 and the maximum value was 1.12. The average I/O value was found to be 0.86 ± 0.13, which shows that in general the indoor air quality is affected by outdoor pollution. This then becomes the basis for the assumption that the indoor concentration can be estimated from the outdoor concentration.

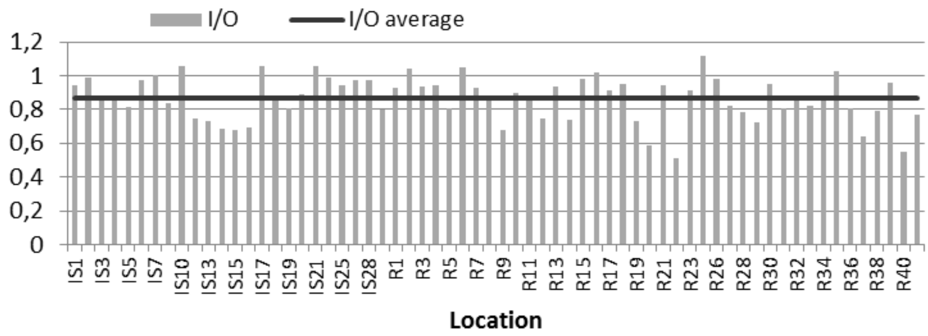

Figure 6 I/O Value for Each House Sampling.

3.2 Selection of Interpolation Method

To obtain a spatially continuous NO_2 concentration mapping, the pollutant concentration at points where there are no measurement data should be estimated. Concentration prediction can be done with a spatial interpolation method. The methods used were the IDW and Kriging methods. The mappings of the outdoor NO_2 concentrations with the IDW method can be seen in Figure 7 and with the Kriging method in Figure 8.The mappings of the indoor concentrations are shown in Figure 9 and Figure 10, respectively. Comparisons of predicted and measured values are presented in Figure 11 and Figure 12.

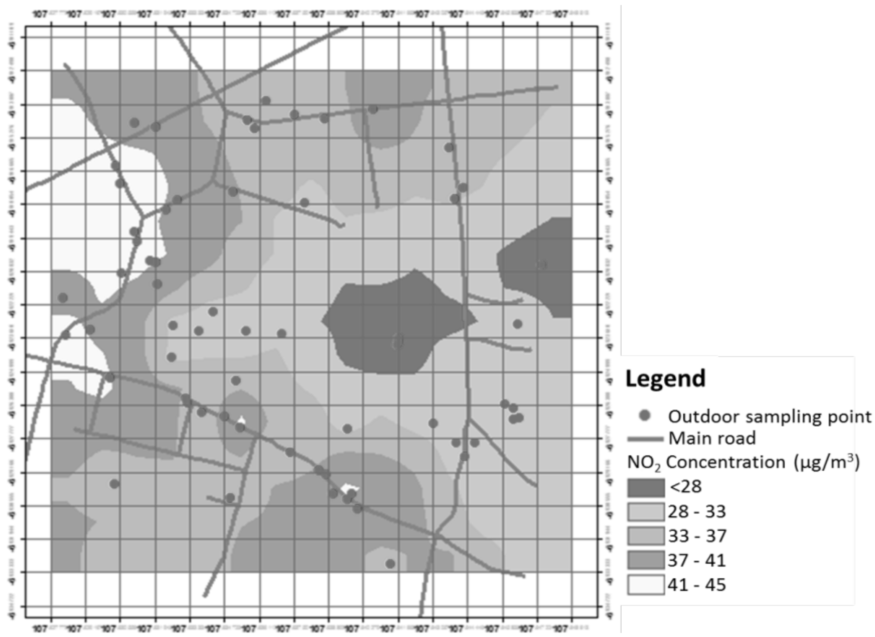

Figure 7 Interpolation of Outdoor NO_2 with IDW Method.

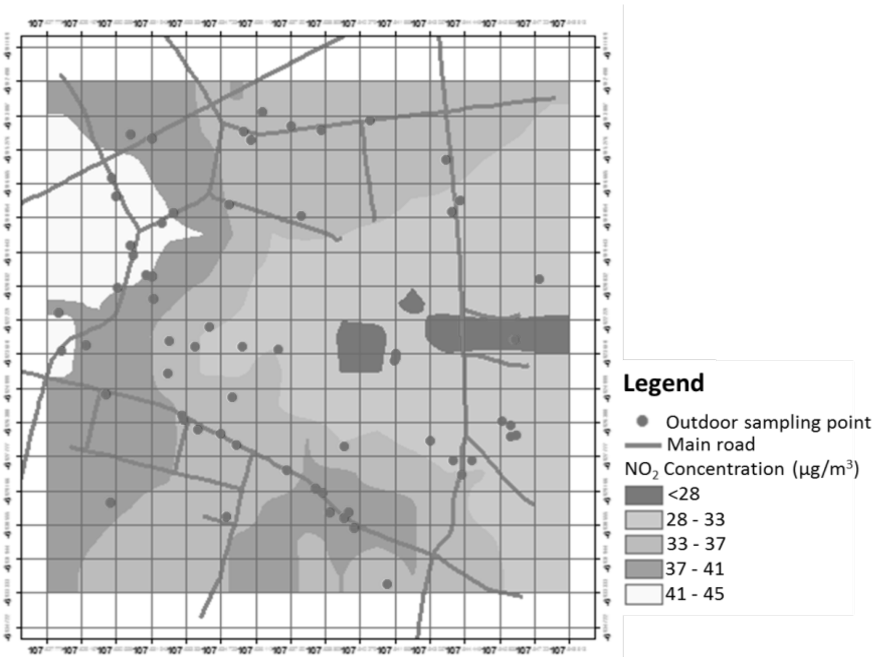

Figure 8 Interpolation of Outdoor NO_2 with Kriging Method.

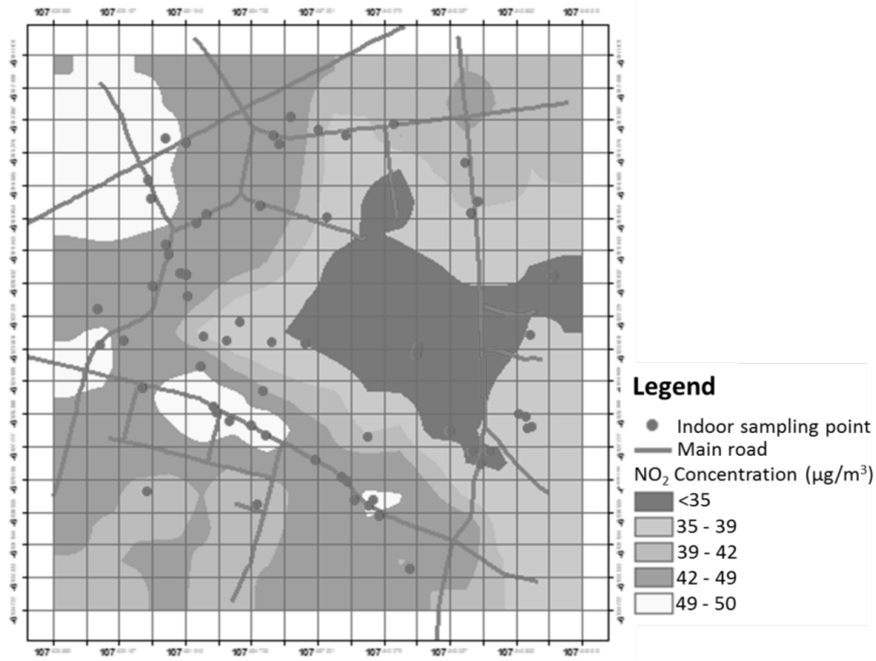

Figure 9 Interpolation of Indoor NO_2 with IDW Method.

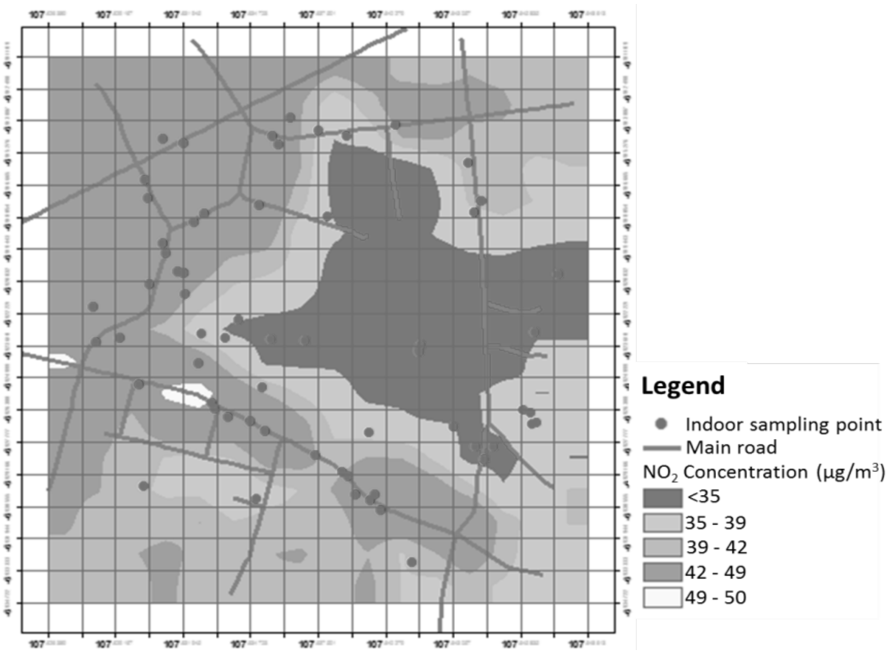

Figure 10 Interpolation of Indoor NO_2 with Kriging Method.

From the interpolated mappings of outdoor concentrations (Figure 7 and Figure 8) it can be seen that there is a similarity between the results of the IDW method (Figure 7) and the Kriging method (Figure 8). The difference is more clearly seen for the lowest concentrations. However, the pattern of interpolation for indoor NO_2 concentrations resulted from IDW (Figure 9) and Kriging (Figure 10) show significantly different patterns. The difference can also be identified clearly in the graph that compares the predicted value with the values of the interpolation in Figure 11 and Figure 12.

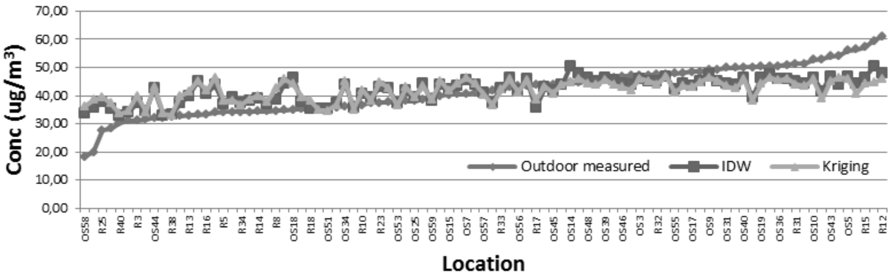

Figure 11 Comparison between Measurement Value and Predicted Value of Outdoor NO_2 Concentrations.

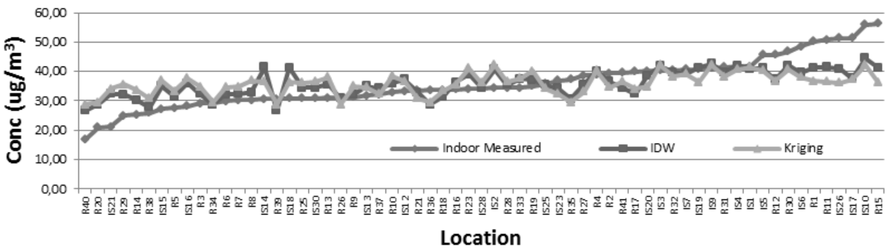

Figure 12 Comparison between Measurement Value and Predicted Value of Indoor NO_2 Concentrations.

Figure 11 shows a comparison between the predicted and measured value of the outdoor NO_2 concentrations, where the difference is relatively small. This is shown by the position of the interpolation points being closer to the line that represents the measurement data. However, the difference between the predicted and the measured values for indoor NO_2 concentrations is more significant than for the outdoor NO_2 concentrations (Figure 12).

The accuracy value indicates how close the predicted value is to the actual value. The accuracy value obtained from the interpolation parameters is measured by root mean square error (RMSE) and standard deviation

(SD). RMSE and SD are parameters that compare measurement data with interpolated data at the same point. The RMSE and SD values of both selected methods can be seen in Table 2. It was found that the smallest RMSE and SD values for the outdoor concentrations resulted from the Kriging method, while for indoor concentrations they resulted from the IDW method.

Table 2 RMSE and SD Values.

Method	***Outdoor***		***Indoor***	
	RMSE (μg/m^3)	**SD (μg/m^3)**	**RMSE (μg/m^3)**	**SD (μg/m^3)**
IDW	5.98	5.96	5.92	5.92
KRIGING	5.45	5.45	6.93	6.93

Table 2 shows that the difference in RMSE and SD values between IDW and Kriging for the outdoor concentrations was only 0.53. This is due to the similarity between the results of IDW and Kriging interpolation. For the indoor concentrations, however, a greater difference between RMSE and SD values was obtained (1.01). This is caused by the presence of other emission sources that may be specific to each house observed [21].

Both geospatial mapping methods are very promising for use in hybrid models. It has been used for developing a traffic-induced NO_2 model to predict indoor air quality [21]. The model has been validated in other areas and yielded an uncertainty degree of 33.3%, which was found to be reasonable.

4 Conclusion

This study showed an I/O average of 0.86 ± 0.13, which indicates an influence of outdoor air on indoor air quality. It suggests that indoor NO_2 concentrations can be predicted by using the results of outdoor measurements [21]. For this purpose it is necessary to map NO_2 concentrations beforehand with an appropriate method. The interpolation method selected for outdoor NO_2 concentration mapping was Kriging, with an RMSE value of 5.45 μg/m^3 and an SD value of 5.45 μg/m^3, while for indoor NO_2 concentration mapping the IDW method was the best fitted with an RMSE value of 5.92 μg/m^3 and an SD value of 5.92 μg/m^3. The selection of the interpolation method was based on the smallest values of RMSE and SD that work both outdoors and indoors, therefore, for the purpose of predicting both indoor and outdoor concentrations in the area of study, IDW was selected.

The results of this study may be useful for impact assessment of roadway emissions on health, especially considering residents living near roadways. These results may be used as an approach to predict indoor NO_2 concentrations inside houses located near roadways based on outdoor measurements, without having to measure indoor levels. The predictions can be used to evaluate the outcome of emission reduction from motor vehicles through action plans within the framework of Environmentally Sustainable Transport (EST).

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References

[1] Soedomo, M., *Scientific Papers Compilation on Air Pollution*. Bandung, Penerbit ITB, 2001. (Text in Indonesian)

[2] Ambika, C., *Technical Guidance on Air Pollution Emergency Mitigation from Mobile Sources*, Jakarta, PT. Amar Binaya Karsa, 2009. (Text in Indonesian)

[3] Srivastava, A. & Jain, V.K., *A Study to Characterize the Suspended Particulate Matter in an Indoor Environment in Delhi, India*, Building and Environment, **42**(5), pp. 2046-2052, 2007.

[4] Godish, T. & J.D. Spengler, *Relationships between Ventilation and Indoor Air Quality: A Review*, Indoor Air, **6**(2), pp. 135-145, 1996.

[5] Yang, W., Lee, K. & Chung, M., *Characterization of Indoor Air Quality Using Multiple Measurements of Nitrogen Dioxide*, Indoor Air, **14**(2), pp. 105-111, 2004.

[6] Lawrence, A.J., Masih, A. & Taneja, A., *Indoor/Outdoor Relationships of Carbon Monoxide and Oxides of Nitrogen in Domestic Homes With Roadside, Urban And Rural Locations in a Central Indian Region*. Indoor Air, **15**(2), pp. 76-82, 2005.

[7] Zou, B., Wilson, J.G., Zhan, F.B. & Zeng, Y., *Air Pollution Exposure Assessment Methods Utilized in Epidemiological Studies*, J Environ Monit, **11**(3), pp. 475-90, 2009.

[8] Isaaks, E.H. & Srivastava, R.M., *An Introduction to Applied Geostatistics.* Oxford University Press.

[9] Beelen, R., Hoek G., Pebema, E., Vienneau, D., de Hoogh, K., Briggs, D.J., *Mapping of Background Air Pollution at a Fine Spatial Scale Across the European Union*. Sci Total Environ, **407**(6), pp. 1852-67, 2009.

[10] Greenland, D. & Yorty, R.A., *The Spatial Distribution of Particulate Concentrations in the Denver Metropolitan Area*. Annals of the Association of American Geographers, **75**(1), pp. 69-82, 1985.

[11] de Leeuw, F.A.A.M. & van Zantvoort, E.D.G., *Mapping of Exceedances of Ozone Critical Levels for Crops and Forest Trees in The Netherlands: Preliminary results*. Environmental Pollution, **96**(1), pp. 89-98, 1997.

[12] Phillips, D.L., Lee, E.H., Hogsett, W.E., *Use of Auxiliary Data for Spatial Interpolation of Ozone Exposure in Southeastern Forests*. Environmentrics, **8**, pp. 43-61, 1997.

[13] Diem, J.E. & Comrie, A.C., *Predictive Mapping of Air Pollution Involving Sparse Spatial Observations*. Environmental Pollution, **119**(1), pp. 99-117, 2002.

[14] Lefohn, A.S., Knudsen, H.P. & McEvoy Jr. L.R., *The Use of Kriging to Estimate Monthly Ozone Exposure Parameters for the Southeastern United States*. Environmental Pollution, **53**(1-4), pp. 27-42, 1988.

[15] Loibl, W., Winiwarter, W., Kopsca, A. & Zueger, J., *Estimating the Spatial Distribution of Ozone Concentrations in Complex Terrain*. Atmospheric Environment, **28**(16), pp. 2557-2566, 1994.

[16] Tayanç, M., *An Assessment of Spatial and Temporal Variation of Sulfur Dioxide Levels over Istanbul, Turkey*, Environmental Pollution, **107**(1), pp. 61-69, 2000.

[17] Sari, P.T. & Driejana, *Measurement of Nitrogen Dioxide Concentrations along Major Roads in Bandung*, Sustainable Infrastructure and Built Environment 2009 International Conference Proceedings, Bandung, 2009.

[18] Driejana, Putri, A.R. & Watson, A.F.R., *Influence of Traffic-related Emissions on Indoor Air Quality in Residential Buildings Adjacent to Roads,* Sustainable Infrastructure and Built Environment 2009 International Conference Proceedings, Bandung, 2009.

[19] Kurniawati, M.C., *Spatial Interpolation Method Comparison for Air Quality Data*, Final Project at Geodesy and Geomatics Engineering, Institut Teknologi Bandung, Bandung, 2009. (Text in Indonesian)

[20] Fitria, A., *Multiple-scale Grid System for Indonesian Environmental Data*, Final Project at Geodesy and Geomatics Engineering, Institut Teknologi Bandung, Bandung, 2009. (Text in Indonesian)

[21] Yudison, A.P. & Driejana, *Modeling of Traffic-Induced NO_2 Concentration to Predict the Indoor Air Quality in Houses near Major Road*, Proceedings of the Eastern Asia Society for Transportation Studies, Jeju, **8**, pp. 174, 2011.